Master of Science

Computer Engineering (Technische Informatik)

MScTI

Description of the course modules

Heidelberg University
Department of Physics and Astronomy

Version 1.10, 13.07.2016

Overview of the course modules

Module	Module Coordinator	ECTS
Fundamentals		
▪ Parallel Computer Architecture (compulsory)	Brüning	6
▪ System Theory (compulsory)	Badreddin	6
▪ C++ Practice	Strzodka	6
▪ Electrical & Optical Communication	Brenner	6
▪ Electronics	Wurz	6
▪ Introduction to High Performance Computing	Fröning	6
▪ Microcontroller Based Embedded Systems	Wurz	6
▪ Reconfigurable Embedded Systems	Kugel	6
Soft Skills		
▪ Tools	all	4
▪ Entrepreneurship	extern	6
Main Subject / Specialization		
▪ Components, Basic Circuits & Simulation	Fischer	6
▪ Full Custom VLSI Design	Fischer	6
▪ Digital Hardware Design	Brüning	6
▪ Digital Semi Custom Design Flow	Brüning	6
▪ Functional Verification	Brüning	6
▪ Advanced Analogue Building Blocks	Fischer	6
▪ Silicon Sensors & Readout Electronics	Fischer	6
▪ GPU Computing	Fröning	6
▪ Parallel Algorithm Design	Strzodka	6
▪ Accelerator Libraries	Strzodka	6
▪ Advanced Parallel Algorithms	Strzodka	6
▪ Advanced Parallel Computing	Fröning	6
▪ FPGA Coprocessors	Kugel	6
▪ High Performance Interconnection Networks	Brüning	6
▪ Parallel Algorithms, Application Computing	Bastian	8
▪ Parallel Solution of Large Linear Systems	Bastian	8
▪ Introduction to Photonics	Brenner	6
▪ Computational Optics	Brenner	6
▪ Physics of Imaging	Jähne	4
▪ Digital Image Processing	Jähne	8
▪ Modern Image Sensors	Jähne	2
▪ Pattern Recognition	Hamprecht	8
▪ Advanced System Theory	Badreddin	6
▪ Design of Autonomous Systems	Badreddin	6
▪ Digital Control	Badreddin	6
▪ Data Acquisition	Badreddin	6
▪ Design of Reliable and Dependable Systems	Badreddin	6
▪ Modeling, optimization and control of mechanical systems	Mombaur	8

Structure of Courses

All in all, the following modules have to be completed successfully (120 CP):

▪ 3 modules from „Fundamentals“	18 CP
▪ 5 modules from „Main Subject / Specialization“	30 CP
▪ 2 modules from „Free Courses”	12 CP
▪ 2 or more modules from „Soft Skills“	12 CP
▪ seminar	4 CP
▪ student research project	14 CP
▪ master thesis with final colloquium	30 CP

Fundamentals

The following modules from “Fundamentals” are compulsory and have to be completed (mandatory modules):

- Parallel Computer Architecture
- System Theory

As an elective you can choose any other subject listed above in “Fundamentals”.

Soft Skills

All in all, 12 CP must be completed in the field of soft skills, 2 of which are integrated in the seminar. For the remaining 10 CP the following courses can be chosen:

- Tools (4 CP),
- Entrepreneurship (6 CP),
- Courses from the University course program classified as soft skill courses,
- Language Courses (6 CP maximum).

Seminar

For the seminar 2 CP are allocated as soft skills in addition to 4 CP for the professional contents.

Seminar: 4 CP (professional contents) + 2 CP (soft skills)

Main Subject / Specialization

In principle, advanced students can choose their in-depth modules freely according to the examination rules / regulations. We recommend, however, following one of the model curricula completing an exceptional specialization in a certain field of Computer Engineering. When completing a sufficient number of modules in such a specialization during your studies, this specialization will be documented explicitly in your Master Certificate.

This is a list of model curricula and the modules required in each case:

1. Microelectronics

3 compulsory modules:	- Components, Basic Circuits & Simulation
	- Digital Hardware Design
	- Full Custom VLSI Design
2 elective modules from:	- Advanced Analog Building Blocks

- Digital Semicustom Design Flow
- Functional Verification
- Microcontroller Based Embedded Systems
- Reconfigurable Embedded Systems
- Silicon Sensors & Readout Electronics

2. Application Specific Computing

3 compulsory modules:	- GPU Computing - Parallel Algorithm Design - Reconfigurable Embedded Systems
2 elective modules from:	- Accelerator Libraries - Advanced Parallel Algorithms - Advanced Parallel Computing - FPGA Coprocessors - High Performance Interconnection Networks - Microcontroller Based Embedded Systems - Parallel Algorithms, Application Computing - Parallel Solution of Large Linear Systems

3. Photonics & Visual Data Processing

Attention: From winter term 2016/17 on the specialization "Photonics & Visual Data Processing" will be closed for students beginning their studies.

3 compulsory modules:	- Electrical & Optical Communication - Introduction to Photonics - Physics of Imaging
2 elective modules from:	- Computational Optics - Digital Image Processing - Pattern Recognition

4. Intelligent Autonomous Systems

3 compulsory modules:	- Advanced System Theory - Design of Autonomous Systems - Digital Control
2 elective modules from:	- Data Acquisition - Design of Reliable and Dependable Systems - Image Processing - Microcontroller Based Embedded Systems - Modeling, optimization and control of mechanical systems - Parallel Solution of Large Linear Systems - Pattern Recognition - Reconfigurable Embedded Systems - Silicon Sensors & Readout Electronics

Overview of the course modules

Fundamentals:

<table>
<tr><td colspan="2">Code:
MScTI_PCA</td><td colspan="3">Course Title:
Parallel Computer Architecture</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. U. Brüning</td><td colspan="3">Type:
Lecture with exercises / lab / …</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2 hours/week)
• Exercise: practical programming exercises on parallel computer system (2 hours/week)</td></tr>
<tr><td colspan="5">Objectives: The students…
• understand the concepts and principles of parallel processing and the underlying hardware structures,
• will be able to program parallel systems with shared and distributed memory,
• can use the learned structures to develop new architectures of parallel computers.</td></tr>
<tr><td colspan="5">Contents:
• Concepts of Parallel Processing
• SIMD-Architectures
• MIMD-Architectures
• Shared Memory
• Distributed Memory
• Communication and Synchronization
• Multithreading
• Taxonomy of Interconnection Networks
• Point-to-Point INs
• Switched INs, Shuffles, Crossbars, Routing, Latency
• Communication Protocols
• Virtual Shared Memory
• Dataflow Architectures</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
basic knowledge of Computer Architecture</td></tr>
<tr><td colspan="5">Literature: a reading list will be provided in the script
The script will be accessible on the web site of the Computer Architecture Chair</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 30’ oral exam at the end of the semester
At least 50% of the exercises must be passed.</td></tr>
</table>

Code: MScTI_SYSTHEO		**Course Title:** System Theory		
Lecturer: Prof. Dr. sc. techn. E. Badreddin		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** SS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: After completing this course the students will be able to:

- describe nonlinear phenomena and nonlinear dynamical systems,
- analyze nonlinear systems by using phase plane, describing functions and Lyapunov theory,
- design simple nonlinear control systems and
- apply the methods to simple practical examples.

Contents:

- Introduction to nonlinear systems,
- Nonlinear phenomena (limit cycles, bifurcations and chaos),
- Phase plane analysis
- Describing function
- Lyapunov stability
- Design of relay feedback control, time optimal control and sliding control

Prerequisites:	**Recommended Knowledge:**
none	Theory of linear systems (Signals and Systems 1)

Literature:

J.J.-E. Slotine and W. Li, Applied Nonlinear Control, Prentice-Hall, 1991.

H. K. Khalil, Nonlinear Systems, Third Edition, Prentice Hall, 2000.

Form of Testing and Examination: 30’ oral exam

Code: MScTI_ADVCPP		**Course Title:** C++ Practice		
Lecturer: Prof. Dr. R. Strzodka		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** WS

Module Parts and Teaching Methods:

- Lecture (2h)
- Exercise (2h) with homework

Objectives: Students…

- learn all major features of modern C++,
- learn guidelines for an effective programming style,
- understand programming patterns.

Contents:

- A tour of modern C++ from start to end
- Immediate use of new functionality since C++11, e.g.
  constexpr, move refs and ctors, initializer list, lambdas, variadic templates
- How to select among the language features
- Clear and effective programming style

Prerequisites:	**Recommended Knowledge:**
none	Understanding of all basic C++ concepts such as references, classes, inheritance, overloading, templates, STL

Literature:

- Bjarne Stroustrup: A Tour of C++, Addison-Wesley, 2013

Form of Testing and Examination: 50% of points from the exercises are required and there will be an oral (20 min) or written (60 min) examination

Code: MScTI_EOC	**Course Title:** Electrical and Optical Communication			
Lecturer: Prof. Dr. K.-H. Brenner	**Type:** Lecture with exercises			
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: The students ...

- understand the physical basics of signal transport for electrical and optical pathways,
- learn the characteristics of different modulation types and know about the limits concerning signal bandwidth, propagation distance and noise,
- deepen their knowledge about the most common components used in digital communication.

Contents:

- Structure of communication systems
- Fundamentals of electrical communication
- Modulation types
- Wave propagation on wires and cables
- Treatment of Strip-Lines
- High frequency filters and equalization
- Noise characteristics
- Mobile radio communication
- Components of optical communication
- Single/Multimode wave guides
- Lasers and modulation types

Prerequisites:	**Recommended Knowledge:**
none	Basic knowledge in Physics, Signals and Systems 1

Literature:

- J. Ohm, H.D. Lüke, Signalübertragung, Springer Verlag
- K.D. Kammeyer, Nachrichtenübertragung, Teubner Verlag
- G. Grau, W. Freude, Optische Nachrichtentechnik, Springer Verlag

Form of Testing and Examination: Participation in the exercises and 30' oral examination.

Code: MScTI_ELEC		**Course Title:** Electronics		
Lecturer: A. Wurz		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture on “Electronics” (3hours/week)
- Exercise with homework (1 hours/week)

Objectives: Students…

- learn about the application of active and passive components,
- understand the methods of circuit design,
- learn about the operation of electronic circuits.

Contents:

- Resistors, capacitors, inductivities
- Diodes (rectifiers, switches)
- Transistors (amplifier, switches)
- Field-effect transistors (JFET, MOSFET)
- Operational amplifier (amplifier, analog filter)
- Oscillators (LC oscillators, crystal oscillators)
- Phase-locked loop, Laplace transformation
- Power supply circuits
- Transmission of analog and digital signals
- Analog to digital conversion
- Simulation of circuits
- Techniques of electronic design

Prerequisites: none	**Recommended Knowledge:** none

Literature: Horowitz and Hill: The Art of Electronics; Herrmann Hinsch: Elektronik; U. Tietze, Ch. Schenk: Halbleiterschaltungstechnik

Form of Testing and Examination: 15 – 30 min. oral exam or 1h written exam

Code: MScTI_INTROHPC		**Course Title:** Introduction to High Performance Computing		
Lecturer: JProf. Dr. H. Fröning		Type: Lecture with exercise		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture (3 hours/week)
- Exercise with homework (1 hours/week)

Objectives: Students…

- know the most important approaches of how to solve large scale computing problems; this involves hardware as well as software architectures,
- have seen some real world examples in some detail,
- have gained practical experience in implementing a high performance computing solution.

Contents:

- The challenges of HPC
- Hardware architectures
- Software frameworks, in particular MPI
- Short introduction to accelerated computing
- Practical problems and their solutions

Prerequisites: none	**Recommended Knowledge:** Computer architecture basics, parallel programming principles, C, C++, OS basics

Literature: Will be announced by lecturer

Form of Testing and Examination: 15 – 30 min. oral exam or 1h written exam

Code: MScTI_MES		**Course Title:** Microcontroller Based Embedded Systems		
Lecturer: A. Wurz		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture (2h)
- Exercise/ Lab work (2h)

Objectives: Students…

- acquire a knowledge about the application of active and passive electronic components,
- learn methods of the circuit design in a real project,
- learn the installation of a development environment for C program development,
- learn methods of debugging in microprocessors circuits,
- acquire a knowledge about the functionality and programming of microprocessors and peripheral circuits,
- have a change, to implement a own circuit.

Contents:

- project management
- circuit design
- microcontrollers
- mp3 decoder + Ethernet
- power supply (linear regulators +switching regulators)
- selection of components
- CAD program (schematic +layout)
- manufacturing boards
- stuffing boards
- C program development
- test program
- implementing + debugging
- electronic construction techniques

Prerequisites: none	**Recommended Knowledge:** none

Literature:

- Paul Horowitz, Winfield Hill: The Art of Electronics

Form of Testing and Examination: oral examination

Code: MScTI_RES		**Course Title:** Reconfigurable Embedded Systems		
Lecturer: Dr. A. Kugel		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture (2h)
- Practical exercise (lab, 2h) with homework

Objectives: Students…

- understand elements and properties of embedded systems,
- get basic understanding of reconfigurable architectures,
- learn elementary application design methodologies for microprocessors and FPGAs,
- implement and program a sample embedded FPGA platform.

Contents:

- Requirements and specific properties of embedded systems
- Overview on hardware components: microcontrollers, peripherals, FPGAs
- Real-time issues and scheduling
- FPGA design tools: HDL (incl. VHDL tutorial), simulator, debugger
- System-on-Chip architecture – controller, buses and peripherals
- HW/SW co-design
- Embedded system software (stand-alone and real-time kernels)

Prerequisites: none	**Recommended Knowledge:** none

Literature:

- Peter Marwedel: Eingebettete Systeme, SpringerLehrbuch, 1. Auflage 2007
- Th. Flick, H. Liebig: Mikroprozessortechnik, SpringerLehrbuch, 4. Auflage 2004
- H. Bähring: MikrorechnerSysteme, SpringerLehrbuch, 3. Auflage 2002
- Karim Yaghmour: Building Embedded Systems, O'Reilly, April 2003

Form of Testing and Examination: 50% successful exercises plus oral (15 min) or written (60 min) examination

Soft Skills:

Code: MScTI_TOOLS		Course Title: Tools		
Lecturer: tbd		**Type:** Lecture with exercises		
Credit Points: 4	**Workload:** 120 h	**Teaching Hours:** 4 / week	**Language** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture (2 h / week)
- Exercise (2 h / week)

Objectives: On a basic level, students

- know a variety of software tools for various special applications to choose from,
- get acquainted with and can apply special software,
- can work independently with software tools,
- acquire knowledge on structured working methods and learn to organize projects,
- are able to deepen these skills and apply them independently.

Contents:

- version control tools (svn,..)
- mathematical software (Mathematica, Maple)
- data evaluation and plotting (gnuplot)
- software documentation tools (doxygen)
- image formats and drawing tools (gimp, xfig)
- styles and templates (powerpoint, word)
- introduction into Latex
- wikis
- html and xml
- team work, project planning and tele working

Prerequisites:	Recommended Knowledge:
none	none

Literature: announced by lecturer

Form of Testing and Examination: none

Code: MScTI_ES		Course Title: Entrepreneurship		
Lecturer: tbd (external)		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture (2 hours/week)
- Exercise (2 hours/week)

Objectives: Students

- get an overview and basic knowledge of legal aspects of founding and running a company and can apply this knowledge,
- get an overview and basic knowledge of financial aspects of founding and running a business and can apply this knowledge,
- know and can apply basic marketing strategies and tools.

Contents:

- founding a company
- business plans
- legal forms of companies
- finance
- marketing
- human resource management
- accounting
- taxation
- patent law and copyright

Prerequisites:	Recommended Knowledge:
none	none

Literature: announced by lecturer

Form of Testing and Examination: none

Main Subject / Specialization:

Code: MScTI_ANASIM		**Course Title:** Components, Basic Circuits & Simulation		
Lecturer: Prof. Dr. P. Fischer		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture (2h)
- Practical exercise with homework (2h)

Objectives: Students…

- understand the basic operation principles of semiconductor devices,
- know properties of diodes and FETs in more detail,
- know how their properties are modelled and where the limits are,
- can simulate analogue circuits,
- know basic circuit topologies and their properties,
- know how to use small signal models for circuit & frequency analysis.

Contents:

- Semiconductor properties
- Diode and transistor operation
- Voltage and current sources, Thevenin equivalent
- Bode plot, transfer function
- Analogue simulation (dc, ac, transient)
- Modelling of Diode und MOS, large / small signal models
- Basic circuits: current mirror, gain stage, cascode, source follower, differential pair
- Practical exercises with professional simulation tools

Prerequisites:	**Recommended Knowledge:**
none	Introduction to physics

Literature:

- P. R. Gray, P. J. Hurst, S. H. Lewis, R. G. Meyer: Analysis and Design of Analog Integrated Circuits, Wiley & Sons, New York, 1993
- D. A. Johns, K. Martin: Analog Integrated Circuit Design, Wiley & Sons, 1997

Form of Testing and Examination: To be defined by lecturer before beginning of course

<table>
<tr><td colspan="2">Code:
MScTI_ANADESIGN</td><td colspan="3">Course Title:
Full Custom VLSI Design</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. P. Fischer</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2h)
• Practical exercise (2h)</td></tr>
<tr><td colspan="5">Objectives: Students…
• know the design flow from idea to the final chip,
• know properties of a typical modern manufacturing technology,
• can perform all design steps using professional tools,
• can program simple automatized scripts,
• know basics of chip testing.</td></tr>
<tr><td colspan="5">Contents:
• Semiconductor manufacturing
• Technology & Design Rules, technology files
• Layout of components, rules, matching
• Design Rule Check
• Extraction
• Layout versus Schematic Check
• ESD and Antenna rules, latchup
• Test equipment & procedures
• Script programming using skill</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
MScTI_ANASIM</td></tr>
<tr><td colspan="5">Literature:
• Lecture script available online</td></tr>
<tr><td colspan="5">Form of Testing and Examination: To be defined by lecturer before beginning of course</td></tr>
</table>

Code: MScTI_DIGHD		**Course Title:** Digital Hardware Design		
Lecturer: Prof. Dr. U. Brüning		**Type:** Lecture with exercises / lab / …		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture (2 hours/week)
- Exercise: design and simulation of digital hardware with EDA software (2 hours/week)

Objectives: The students **…**

- understand the concepts and principles of hardware design and the methodology for design and verification of hardware structures,
- will be able to use their acquired knowledge to design new and efficient hardware,
- can simulate and verify the developed designs.

Contents:

- Introduction to the principles of hardware design
- use of Hardware Description Languages like Verilog HDL.
- design of combinational and sequential logic.
- overall design flow for Integrated Circuits
- Design descriptions
- Design elements
- Simulation
- Verification of Hardware

Prerequisites: none	**Recommended Knowledge:** basic knowledge of Digital Circuit Design

Literature: a reading list will be provided in the script

The script will be accessible on the web site of the Computer Architecture Chair

Form of Testing and Examination: 30’ oral exam at the end of the semester

At least 50% of the exercises must be passed.

Code: MScTI_DIGDF		**Course Title:** Digital Semi Custom Design Flow		
Lecturer: Prof. Dr. U. Brüning		**Type:** Lecture with exercises / lab / project …		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture … (2 hours/week)
- Exercise: backend processing for ASICs with EDA software (2 hours/week)

Objectives: The students **…**

- deepen their knowledge of the methodology for semi-custom ASIC design,
- will be able to use their acquired knowledge to design very complex chips,
- can run the complete backend design process for modern chip technology.

Contents:

- Advanced methods for design of application specific ICs
- Synthesis of complex hardware systems
- Static Timing Analysis (STA)
- Place&Route of modules and standard cells
- Signal integrity analysis
- Design rule checks
- Generation of mask data
- The SEED-2002 agreement between Cadence Design Systems and the University of Heidelberg allows our students to work and learn with the most modern EDA tools that are usually only used in chip industry.

Prerequisites: none	**Recommended Knowledge:** deeper knowledge of Digital Hardware Design

Literature: a reading list will be provided in the script

The script will be accessible on the web site of the Computer Architecture Chair

Form of Testing and Examination: 30’ oral exam at the end of the semester

At least 50% of the exercises and the chip project must be passed.

<table>
<tr><td colspan="2">Code:
MScTI_DIGVERI</td><td colspan="3">Course Title:
Functional Verification</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. U. Brüning</td><td colspan="3">Type:
Lecture with exercises / lab / …</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture … (2 hours/week)
• Exercise … (2 hours/week)</td></tr>
<tr><td colspan="5">Objectives: The students...
• understand the concepts and principles of functional verification and the methodology,
• for building verification environments,
• learn to verify complex hardware designs.</td></tr>
<tr><td colspan="5">Contents:
• Introduction to the principles of functional verification
• Simulation-Based Verification
• Formal Verification
• Use of Hardware Verification Languages like System Verilog
• Use of Verification Methodologies like OVM
• Verification Planning
• Coverage Models
• Assertion-Based Verification</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
Experience in Digital Hardware design</td></tr>
<tr><td colspan="5">Literature: a reading list will be provided in the script
The script will be accessible on the web site of the Computer Architecture Chair</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 30’ oral exam at the end of the semester
At least 50% of the exercises must be passed.</td></tr>
</table>

Code: MScTI_ANABLOCKS		**Course Title:** Advanced Analogue Building Blocks		
Lecturer: Prof. Dr. P. Fischer		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture (2 hours/week)
- Exercise (2 hours/week)

Objectives: The students **…**

- get a deeper qualitative understanding of the behavior of analogue circuits,
- can quantitatively analyze analogue circuits and extract important figures of merit,
- know a large variety of advanced circuit topologies.

Contents:

- Advanced Transistor properties
- Feedback: properties, mathematical treatment, stability, Nyquist test
- Noise of components and circuits
- Transfer function, impulse response, poles and zeros
- Cascaded amplifiers
- Advanced current mirrors
- Differential circuits, common mode feedback
- DACs and ADCs

Prerequisites: none	**Recommended Knowledge:** MScTI_ANADESIGN

Literature:

- Razavi „Design of analog CMOS integrated circuits“
- J. Millman „Microelectronics“

Form of Testing and Examination: To be defined by lecturer before beginning of course

The following module is imported from the master program in physics:

<table>
<tr><td colspan="2">Code:
MScTI_DET</td><td colspan="3">Course Title:
Silicon Detectors & Readout Electronics</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. P. Fischer</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2 hours/week)
• Exercise with homework (2 hours/week)</td></tr>
<tr><td colspan="5">Objectives: The students …
• know the basic principles of silicon detectors,
• know different sensor types with their properties,
• know real world applications and typical experiments,
• know the basics on how to read out the signals and which figures of merit are of importance.</td></tr>
<tr><td colspan="5">Contents:
• Basics
    o Interactions of particles and photons with matter
    o Semiconductors, doping, diodes, manufacturing technology
    o Spatial resolution, energy resolution, noise…
• Particle Sensors
    o PiN Diodes, Pads, Pixel, Strips
    o DEPFETs, MAPS
    o Non-silicon materials
• Photo Sensors
    o Quantum efficiency, spectral sensitivity, response time
    o APDs, SiPMs, CCDs, CMOS APS, others
• Readout circuits
    o Charge amplifier, Transimpedance amplifier, bandwidth, noise
    o Readout chips for strip- and pixel detectors
• Applications</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
Basic knowledge in Electrodynamics, Quantum Mechanics and Solid State Physics</td></tr>
<tr><td colspan="5">Literature:
• Semiconductor Devices, S. M. Sze, Wiley, ISBN 0471874248
• Semiconductor Radiation Detectors, G. Lutz, Springer, ISBN 3540648593
• Pixel Detectors, Rossi/Fischer/Rohe/Wermes, Springer, ISBN 3540283323</td></tr>
<tr><td colspan="5">Form of Testing and Examination: To be defined by lecturer before beginning of course</td></tr>
</table>

Code: MScTI_GPU		**Course Title:** GPU Computing		
Lecturer: JProf. Dr. H. Fröning		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture on “GPU Computing” (2 hours/week)
- Exercise with homework (2 hours/week)

Objectives: Students…

- know the architecture of GPUs,
- are able to create simple GPU programs in CUDA,
- understand the factors that determine the performance of GPU programs,
- are able to optimize GPU programs for better performance.

Contents:

- Parallel Programming: Problem Decomposition, Algorithm Selection & Implementation Mechanisms
- GPU Programming Model
- Introduction to CUDA
- Optimizing Performance
- Introduction to OpenCL

Prerequisites:	**Recommended Knowledge:**
none	Parallel programming, C++ programming skills

Literature: T.G. Mattson, B.A. Sanders, B.L. Massingill: Parallel Patterns for Parallel Programming, Addison Wesley 2004; D.B. Kirk, W.W. Hwu: Programming Massively Parallel Processors, Morgan-Kaufmann 2010

Form of Testing and Examination: 15-30’ oral exam or 1h written exam

<table>
<tr><td colspan="2">Code:
MScTI_PAD</td><td colspan="3">Course Title:
Parallel Algorithm Design</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. R. Strzodka</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German / English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2h)
• Exercise (2h) with homework</td></tr>
<tr><td colspan="5">Objectives: Students…
• know the available parallelism and how to use it,
• understand the tradeoffs in parallel algorithm design,
• learn different design patterns for parallel algorithms.</td></tr>
<tr><td colspan="5">Contents:
• Multiple levels of parallelism
• Parallel data access
• Communication vs. computation
• Latency vs. throughput
• Work efficiency vs. step efficiency
• Locality vs. parallelism
• Parallel design patterns</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
Basic C++, CUDA, MScTI_GPU</td></tr>
<tr><td colspan="5">Literature:
• Will be announced by the lecturer</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 50% of points from the exercises are required and there will be an oral (20 min) or written (60 min) examination</td></tr>
</table>

Code: MScTI_ACCLIB		**Course Title:** Accelerator Libraries		
Lecturer: Prof. Dr. R. Strzodka		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** SS

Module Parts and Teaching Methods:

- Lecture (2h)
- Exercise (2h) with homework

Objectives: Students…

- understand the potential of accelerators to speed up execution,
- learn how to use accelerators without low-level programming,
- solve many problem classes quickly with accelerator libraries.

Contents:

- Overview of accelerator programming
- General STL-like libraries
- Libraries for dense linear algebra
- Libraries for sparse linear algebra
- Specialized libraries
- Libraries on clusters of accelerators

Prerequisites:	**Recommended Knowledge:**
none	Basic C++

Literature:

- Will be announced by the lecturer

Form of Testing and Examination: 50% of points from the exercises are required and there will be an oral (20 min) or written (60 min) examination

<table>
<tr><td colspan="2">Code:
MScTI_ADVALG</td><td colspan="3">Course Title:
Advanced Parallel Algorithms</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. R. Strzodka</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German / English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2h)
• Exercise (2h) with homework</td></tr>
<tr><td colspan="5">Objectives: Students…
• learn advanced transformations to improve parallelism and locality,
• know different options for compact data representation,
• understand the design of efficient, parallel, hierarchical algorithms.</td></tr>
<tr><td colspan="5">Contents:
• The lectures MScTI_PAD and MScTI_ADVALG can be attended in the same semester in parallel. MScTI_PAD looks at more topics in breadth, while MScTI_ADVALG looks at fewer topics in depth.
• Loop transformations
• Renumbering and coloring
• Data representation
• Precision and accuracy
• Efficiency of hierarchical algorithms</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
Basic C++ and CUDA
MScTI_GPU, MScTI_PAD in parallel</td></tr>
<tr><td colspan="5">Literature:
• Will be announced by the lecturer</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 50% of points from the exercises are required and there will be an oral (20 min) or written (60 min) examination</td></tr>
</table>

Code: MScTI_APC		**Course Title:** Advanced Parallel Computing		
Lecturer: Prof. Dr. U. Brüning / JProf. Dr. H. Fröning		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** SS

Module Parts and Teaching Methods:

- Lecture … (2 hours/week)
- Exercise: homework and practical programming exercises on parallel architectures (2 hours/week)

Objectives: The students **…**

- understand advanced concepts and principles of parallel architectures,
- will be able to develop optimized programs for parallel architectures,
- can use the learned structures to develop new architectures.

Contents:

- Principles of parallel computing
- Shared memory architectures
- Programming paradigms, communication and synchronization primitives
- Consistency models and scalable cache coherence
- Multi-/many-core and multi-threading architectures
- Exemplary applications and benchmarks
- Emerging architectures and programming paradigms, green computing

Prerequisites:	**Recommended Knowledge:**
none	MScTI_PCA, MScTI_INTROHPC, C++, OS basics

Literature: a reading list will be announced by the lecturer

Form of Testing and Examination: 15-30’ oral exam or 1h written exam

Code: MScTI_FPGA		Course Title: FPGA Coprocessors		
Lecturer: Dr. A. Kugel		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture on "FPGA Coprocessors" (2 hours/week)
- Exercise with homework (2 hours/week)

Objectives: Students…

- know the architecture of FPGA devices and FPGA coprocessors,
- are able to create simple FPGA programs,
- understand the design space of FPGA coprocessors and are able to map simple applications to a specific FPGA coprocessor.

Contents:

- Reconfigurable Computing Hardware
  - FPGA Device Architecture and Features
  - Reconfigurable Computing Architectures
  - (Re-)Configuration Management
- Programming Reconfigurable Systems
  - Compute Models and System Architectures
  - Programming FPGA Applications in VHDL
  - Data- and Control- Flow Graphs
  - High-Level Synthesis Tools
- Mapping Designs to Reconfigurable Platforms
  - Technology Mapping
  - Datapath Optimizations
- Projects: Implementing Applications with FPGAs
- Computation, Image-processing, I/O oriented

Prerequisites: none	**Recommended Knowledge:** FPGA and HDL fundamentals (e.g. from MScTI_RES)

Literature: Scott Hauck & André Dehon: Reconfigurable Computing; Morgan Kaufmann, 2008

Form of Testing and Examination: 50% successful exercises plus oral (15 min) or written (60 min) examination

<table>
<tr><td colspan="2">Code:
MScTI_HPNET</td><td colspan="3">Course Title:
High Performance Interconnection Networks</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. U. Brüning /
JProf. Dr. H. Fröning</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (2 hours/week)
• Exercise with homework (2 hours/week)</td></tr>
<tr><td colspan="5">Objectives: The students …
• understand the concepts and principles of interconnection networks,
• will be able to configure and use interconnection networks for given demands,
• can use the learned structures to develop new high performance interconnection networks.</td></tr>
<tr><td colspan="5">Contents:
• Topologies, Switching, Routing, Flow Control
• Fault tolerance and Deadlocks
• Collective Communications
• Congestion Management
• Network Interfaces
• On-Chip Networks
• Performance Evaluation and Simulation</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
MScTI_PCA, MScTI_APC</td></tr>
<tr><td colspan="5">Literature: a reading list will be provided in the script
The script will be accessible on the web site of the Computer Architecture Group</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 30‘ min. oral exam or 2h written exam</td></tr>
</table>

The following module is imported from the master program in computer science:

<table>
<tr><td colspan="2">Code:
IPHR</td><td colspan="3">Course Title:
Parallel Algorithms, Application Computing (Paralleles Höchstleistungsrechnen)</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. P. Bastian/ Dr. S. Lang</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
8</td><td>Workload:
240h</td><td>Teaching Hours:
6 / week</td><td>Language:
German</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
Lecture 4 SWS
Exercises 2 SWS</td></tr>
<tr><td colspan="5">Objectives: The student
knows different architectures for high-performance computers,
knows synchronization mechanisms in parallel systems including performance aspects,
can handle the most important programming paradigms for parallel systems,
is able to solve basic synchronization tasks,
understands the parallelization of linear algebra algorithms,
is able to assess the performance of a parallel program.</td></tr>
<tr><td colspan="5">Contents:
Systems with global address space
Cache coherence
Systems with local address space and message passing
critical sections, condition synchronization, semaphore
posix threads
programming of graphics cards
message passing theory, MPI
client server model, remote procedure call
Assessment of parallel algorithms
load balancing
dense linear algebra algorithms, solution of sparse linear systems
particle methods
parallel sorting</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
knowledge of a higher-level programming language (preferably C, C++), knowledge of data structures and algorithms</td></tr>
<tr><td colspan="5">Literature:</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Successful participation in the exercises (Minimum 50%) and final examination.</td></tr>
</table>

The following module is imported from the master program in computer science:

<table>
<tr><td colspan="2">Code:
IPLGG</td><td colspan="3">Course Title:
Parallel Solution of Large Linear Systems
(Parallele Lösung großer Gleichungssysteme)</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. P. Bastian</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
8</td><td>Workload:
240h</td><td>Teaching Hours:
6 / week</td><td>Language:
German</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture 4 SWS
• Exercises 2 SWS</td></tr>
<tr><td colspan="5">Objectives: The student
• knows the discretization of scalar elliptic partial differential equations with the finite element method,
• understands the abstract concept of subspace correction methods,
• is able to apply this to domain decomposition and multigrid methods,
• understands the convergence theory for these methods,
• is able to implement these methods on a parallel system and can judge the performance of the methods.</td></tr>
<tr><td colspan="5">Contents:
• Basis of Finite Element methods for elliptic partial differential equations
• Subspace correction methods
• Overlapping and non-overlapping domain decomposition methods with convergence theory
• Geometric multigrid methods with convergence theory
• Algebraic multigrid methods</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
knowledge of a higher-level programming language (preferably C++), knowlege of numerical methods for differential equations</td></tr>
<tr><td colspan="5">Literature:</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Successful participation in the exercises (Minimum 50%) and final examination.</td></tr>
</table>

Code: MScTI_PHOT		**Course Title:** Introduction to Photonics		
Lecturer: Prof. Dr. K.-H. Brenner		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German	**Term:** WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: The students ...

- learn about the fundamental properties and mathematical descriptions of light,
- get familiar with the various passive and active components used in optics,
- understand the differences between propagation in homogenous and inhomogeneous media,
- understand the basics concepts of light detection and light generation.

Contents:

- Ray optics
- Electromagnetic treatment of optics
- Polarisation
- Scalar wave optics
- Fourier optics
- Light propagation in wave guides
- Light propagation in layered media
- Resonators
- Photo detectors
- Light emitting diodes and semiconductor lasers

Prerequisites: none	**Recommended Knowledge:** Basic knowledge in Physics

Literature:

- B. E. A. Saleh, M. C. Teich: Grundlagen der Photonik, Wiley-VCH

Form of Testing and Examination: Participation in the exercises and 30' oral examination.

Code:
MScTI_COMPO

Course Title:
Computational Optics

Lecturer:
Prof. Dr. K.-H. Brenner

Type:
Lecture with exercises

Credit Points:	Workload:	Teaching Hours:	Language:	Term:
6	180h	4 / week	German	WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: The students ...

- deepen their knowledge about vector mathematics in the context of ray optics,
- combine the fast Fourier transformation (FFT) with the two-dimensional sampling theorem and thus understand the limitations of scalar propagation methods,
- apply results of linear algebra to rigorous optical diffraction methods,
- understand the validity range for the various calculation methods.

Contents:

- Vectorial ray tracing in optical systems
- Skalar wave propagation in homogeneous media
- Vectorial wave propagation in layered media
- Rigorous methods in the frequency domain: The RCWA
- Rigorous methods in the time domain: The FDTD

Prerequisites:
none

Recommended Knowledge:
Basic knowledge in Physics, Introduction to Photonics

Literature:

- Born und Wolf, Principles of Optics, Cambridge University Press
- Jackson, Classical Electrodynamics, Wiley Verlag
- Tavlove, Computational Electrodynamics, Artech House

Form of Testing and Examination: Participation in the exercises and 30' oral examination.

The following module is imported from the master program in physics:

<table>
<tr><td colspan="2">Code:
MWInf6 (Physics)</td><td colspan="3">Course Title:
Digital Image Processing</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. B. Jähne</td><td colspan="3">Type:
Lecture with Exercise</td></tr>
<tr><td>Credit Points:
8</td><td>Workload:
240h</td><td>Teaching Hours:
6 / week</td><td>Language:
English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
Lecture (4h)
Exercise (2h)</td></tr>
<tr><td colspan="5">Objectives: The students
learn how to analyze signals from time series, images, and any kind of multidimensional signals and to apply it to problems in natural sciences, life sciences and technology.</td></tr>
<tr><td colspan="5">Contents:
Continuous and discrete signals, sampling theorem, signal representation
Fourier transform
Random variables and fields, probability density functions, error propagation
Homogeneous and inhomogeneous point operations
Neighborhood operations, linear and nonlinear filters, linear system theory
Geometric transformations and interpolation
Multi-grid signal presentation and processing
Averaging, edge and line detection, local structure analysis, local phase and wave numbers
Motion analysis in image sequences
Segmentation
Regression, globally optimal signal analysis, variation approaches, steerable and nonlinear filtering, inverse filtering
Morphology and shape analysis, moments, Fourier descriptors
Bayesian image restoration
Object detection and recognition</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
UKInf1 (Physics)</td></tr>
<tr><td colspan="5">Literature: B. Jähne, Digital Image Processing, 6th edition, Springer 2005</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Written examination</td></tr>
</table>

The following module is imported from the master program in physics:

Code: MWInf5 (Physics)		**Course Title:** Physics of Imaging		
Lecturer: Prof. Dr. B. Jähne		**Type:** Lecture		
Credit Points: 4	**Workload:** 120h	**Teaching Hours:** 4 / week	**Language:** English	**Term:** SS
Module Parts and Teaching Methods: • Lecture				
Objectives: The students • learn the basics of the Physics of Imaging; common principles and techniques of imaging for atomic to astronomical scales.				
Contents: • Projective geometry, optics, wave optics, Fourier optics and lens aberrations • Radiometry of imaging • Methods of imaging: scanning electron microscopy, X-ray, EDX, FLIM,FRET , fluorescence imaging, near-field imaging • CCD and CMOS technology • Holography, ultrasound imaging, CT- computer tomography, magnetic resonance imaging… • Satellite imaging, synthetic aperture radar, radio astronomy				
Prerequisites: none		**Recommended Knowledge:** UKInf2, PEP1-PEP4		
Literature: B. Jähne, Digital Image Processing, 6th edition, Springer 2005				
Form of Testing and Examination: Oral examination				

<table>
<tr><td colspan="2">Code:
MScTI_MIS</td><td colspan="3">Course Title:
Modern Image Sensors</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. B. Jähne</td><td colspan="3">Type:
Lecture</td></tr>
<tr><td>Credit Points:
2</td><td>Workload:
60h</td><td>Teaching Hours:
compact course</td><td>Language:
English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture</td></tr>
<tr><td colspan="5">Objectives: The students
• learns all the basic knowledge about image sensors one should know to apply image processing techniques.</td></tr>
<tr><td colspan="5">Contents:
• Radiation detection: Basic principle of quantum detectors, quantum efficiency and responsivity, dark signal, overall system gain, spectral sensitivity;
• Non-silicon solid-state imaging: InGaAs, HgCdTe, InSb, QWIP, superlattice detectors; indirect (thermal) detectors: pyroelectricity, microbolometers
• Imaging detectors: the charge-coupled device (CCD), CCD sensor architecture, frame transfer, interline transfer, electronic shutter, microlens arrays; CMOS imaging sensors and active pixels, scientific CMOS sensors, color and spectral sensors, high-speed imaging, artefacts of image sensors
• Standard interfaces for digital cameras: Camera Link, Camera Link HS, CoaxPress (CXP), Firewire (IEEE1394), USB2, USB3 Vision, GigE Vision, towards a standardized interface: GenICam
• Performance characterization for image sensors: EMVA 1288 standard, noise model for a linear camera, photon transfer method, signal to noise ratio (SNR), signal saturation, absolute sensitivity threshold, dynamic range (DR), Dark current and auto-saturation time, Spatial nonuniformities and defective pixel: spatial variances, spectrogram method, logarithmic histograms, profiles
• Practical issues: Measuring equipment for camera performance characterization, Application-oriented camera selection according to different criteria</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
BSc Applied Computer Science</td></tr>
<tr><td colspan="5">Literature: will be given at course</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Oral examination</td></tr>
</table>

The following module is imported from the master program in physics:

<table>
<tr><td colspan="2">Code:
MWInf7 (Physics)</td><td colspan="3">Course Title:
Pattern Recognition</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. F. Hamprecht</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
8</td><td>Workload:
240h</td><td>Teaching Hours:
6 / week</td><td>Language:
English</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
Lecture
Exercise</td></tr>
<tr><td colspan="5">Objectives: The students
given a huge bunch of data, find out what’s in it; build automated diagnostic systems or expert systems that automatically learn to make reliable predictions from a training set of examples. Lectures and exercises will be interwoven and allow you to build such systems by yourself; real-life examples will be drawn from for the application areas named below.</td></tr>
<tr><td colspan="5">Contents:
Curse of dimensionality
Variable selection and dimension reduction for high-dimensional data
Unsupervised learning: Cluster analysis
Supervised learning: Regression
Supervised learning: Classification by means of neural networks, support vector machines, etc.
Graphical models
Applications: Data mining, industrial quality control, process monitoring, astrophysics, medicine, life sciences</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
UKInf1, Knowledge about Linear Algebra, Probability, Statistics</td></tr>
<tr><td colspan="5">Literature: Pattern Classification (2nd ed.) by Richard O. Duda, Peter E. Hart and David G. Stork. Wiley, 2000.</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Defined at lecture start</td></tr>
</table>

Code: MScTI_ASYSTHEO		Course Title: Advanced System Theory		
Lecturer: Prof. Dr.sc.techn. E. Badreddin		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: After completing this course the students will be able to:

- describe and analyze systems by using fuzzy sets, artificial neural networks or game theory and
- design control systems for some relevant examples based on the aforementioned methods.

Contents:

The course consists of three parts:

Fuzzy sets and fuzzy control

- Definitions, operations and relations with fuzzy sets
- Linguistic modelling of dynamic systems
- Linguistic system analysis and control

Artificial Neural Networks

- Introduction, motivation and definitions
- Modelling of neural networks
- Processing artificial neural networks
- Application of artificial neural networks in control systems

Game Theory

- Introduction (motivation, definitions, description of a game)
- Strategic games and extensive games
- Differential games
- Application of game theory in control systems

Prerequisites:	**Recommended Knowledge:**
none	System Theory, Theory of linear systems

Literature:

Y. C. Shin and C. Xu Intelligent Systems: Modeling, Optimization, and Control. CRC Press, 2008.

J. Engwerda, LQ Dynamic Optimization and Differential Games. J. Wiley, 2005.

Form of Testing and Examination: 30’ oral exam

Code: MScTI_AUTO		**Course Title:** Design of Autonomous Systems		
Lecturer: Prof. Dr.sc.techn. E. Badreddin		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: After completing this course the students will be able to:

- understand the design requirements and formulate the system specifications,
- formulate the problem,
- decompose the problem of the design of autonomous mechatronic systems into sub-problems,
- choose an architecture in which the solutions of the sub-problems leads to the overall design,
- find an implementation to each of the posed sub-problems,
- integrate the individual implementation into the selected overall system architecture,
- understand the practical constraints and requirements of the real-time realization and
- demonstrate the whole design process by using Autonomous Wheeled-mobile robots.

Contents:

- Introduction to autonomous systems
- The design problem
- Control structure
- Behavior fusion
- Kinematics
- Kinematic control
- Collision avoidance
- Navigation
- Higher-level behavior
- Implementation
- Overall system specifications

Prerequisites: none	**Recommended Knowledge:** System Theory, theory of linear systems (Signals and Systems 1)

Literature:

Badreddin, E., "Control and System Design of Wheeled Mobile Robots", Habilitations-schrift, 1997.

Dudek, G., Jenkin, M., Computational Principles of Mobile Robotics, Cambridge University Press, 2000.

Form of Testing and Examination: 30’ oral exam

<table>
<tr><td colspan="2">Code:
MScTI_DIGCTRL</td><td colspan="3">Course Title:
Digital Control in Real Time</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr.sc.techn. E. Badreddin</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German / English</td><td>Term:
SS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture: 2 hours/week
• Exercise: 2 hours/week</td></tr>
<tr><td colspan="5">Objectives: After completing this course the students will be able to:
• understand the sampling process,
• use the z-transform for solving control problems,
• model, analyze and design digital control systems and
• implement a control system in real time.</td></tr>
<tr><td colspan="5">Contents:
• Introduction to digital signals and systems
• Sampling theory and z-Transform
• Modelling of discrete-time dynamic systems
• Analysis of discrete-time dynamic systems
• Digital design of control systems
• Real-time implementation
• Practical aspects of the implementation and operation</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
System Theory, Theory of linear systems</td></tr>
<tr><td colspan="5">Literature:
K. J. Aström and B. Wittenmark, Computer-controlled systems. Prentice Hall, 1997.
M. S. Fadali and A. Visioli, Digital Control Engineering: Analysis and Design. Academic Press, 2009</td></tr>
<tr><td colspan="5">Form of Testing and Examination: 30’ oral exam</td></tr>
</table>

Code: MScTI_DAQ		**Course Title:** Data Acquisition		
Lecturer: Prof. Dr.sc.techn. E. Badreddin		**Type:** Lecture with exercises		
Credit Points: 6	**Workload:** 180h	**Teaching Hours:** 4 / week	**Language:** German / English	**Term:** WS

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: After completing this course the students will be able to:

- understand the components of a Data Acquisition System (DAS),
- describe the basic principles, which dominates each stage of a DAS and
- implement a DAS for a given application.

Contents:

- Overview of Sensors and Signals
- Analogue and digital inputs and outputs
- Hardware and software for data acquisition
- Signal conditioning
- Data communication and data transfer
- Signal processing

Prerequisites:	**Recommended Knowledge:**
none	Digital control in real time, Sensor technologies

Literature:

J. Park and S. Mackay Practical Data Acquisition for Instrumentation and Control Systems (IDC Technology). Newnes, 2003.

H. R. Taylor, Data Acquisition for Sensor Systems. Springer, 2010.

Form of Testing and Examination: 30’ oral exam

<table>
<tr><td colspan="2">Code:
MScTI_RELSYS</td><td colspan="3">Course Title:
Design of Reliable and Dependable Systems</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr.sc.techn. E. Badreddin</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
6</td><td>Workload:
180h</td><td>Teaching Hours:
4 / week</td><td>Language:
German / English</td><td>Term:
WS</td></tr>
</table>

Module Parts and Teaching Methods:

- Lecture: 2 hours/week
- Exercise: 2 hours/week

Objectives: After completing this course the students will be able to:

- understand und describe the basic properties of reliable and dependable systems,
- utilize problem specific modelling methods to describe a variety of systems,
- analyze technical systems with respect to their reliability and dependability,
- apply methods and techniques for the design and realization of reliable and dependable systems.

Contents:

- Introduction
- Reliability and Dependability Measures
- Boolean Reliability Modelling
- Markov Modelling
- Petri Nets
- Redundancy Techniques for Hardware and Software
- Fault Injection
- Description of Dynamic Systems
- System Architectures and Topologies
- Dynamic Safety Control
- Monitoring and Diagnosis
- Human Reliability
- System Design Methods and Techniques
- Application Examples from Mobile Robotics, Avionics, and Medical Technology

Prerequisites:	**Recommended Knowledge:**
none	Theory of linear systems (Signals and Systems 1)

Literature:

M. Walter, W. Schneeweiss, „The Modeling World of Reliability/Safety Engineering“, LiLoLe-Verlag GmbH, Hagen, Germany, 2005.

Uwe Kay Rakowsky, “System-Zuverlässigkeit“, Hagen/Westfalen: LiLoLe-Verlag, 2002. Paperback, 444 Seiten, ISBN 3-934447-22-8.

Form of Testing and Examination: 30’ oral exam

<table>
<tr><td colspan="2">Code:
MScTI_MORMS</td><td colspan="3">Course Title:
Modeling, Optimization and Control of Mechanical Systems</td></tr>
<tr><td colspan="2">Lecturer:
Prof. Dr. Katja Mombaur</td><td colspan="3">Type:
Lecture with exercises</td></tr>
<tr><td>Credit Points:
8</td><td>Workload:
240h</td><td>Teaching Hours:
4 + 2 / week</td><td>Language:
English</td><td>Term:
every 2 y</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
• Lecture (4 hours / week)
• Programming exercises with software tools (2 hours / week)</td></tr>
<tr><td colspan="5">Objectives: The students…
• know principles of modeling, optimization and control of dynamic processes, in particular mechanical systems, and can explain and apply them,
• are familiar with nonlinear optimization and optimal control methods and can compare and evaluate different mathematical approaches,
• can model, classify and analyze complex motions of mechanical systems, e.g. in robotics or biomechanics, and investigate specific properties such as stability,
• know how to use software tools based on C++ and Lua for modeling, simulation, optimization and visualization of mechanical systems,
• are capable to solve optimal control problems numerically and to evaluate the quality of the solution.</td></tr>
<tr><td colspan="5">Contents:
• Dynamic process modeling
• Mechanical basics, kinematics, dynamics & multibody system modeling
• Simulation of motions
• Nonlinear optimization
• Direct methods for optimal control problems
• Elementary control principles and basics of system dynamics
• Open-loop and closed loop control of motions
• Modeling bipedal walking and running motions in humans and robots
• Stability of motions
• Simulation and visualization of mechanical systems
• Modeling multibody systems with RBDL (Rigid Body Dynamics Library)
• Solution of optimal control problems with MUSCOD-II for different mechan. examples</td></tr>
<tr><td colspan="2">Prerequisites:
Programing skills in C/C++; basic knowledge in numerical analysis</td><td colspan="3">Recommended Knowledge:
Lectures “Introd. to Numerical mathematics”, "Algorithmic optimization", "Numerical mathematics 1"; Knowledge in Matlab/Octave</td></tr>
<tr><td colspan="5">Literature:
• J. T. Betts: Practical Methods for Optimal Control Using Nonlinear Programming
• D. Greenwood: Principles of Dynamics
• J. Craig: Introduction to Robotics - Mechanics and Control
• J. Nocedal, S. Wright: Numerical Optimization
• B. Siciliano, et al: Robotics - Modeling, Planning and Control</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Written exam at the end of the semester.
Successful completion of 50% of the exercises is required to be accepted to exam.</td></tr>
</table>

<table>
<tr><td colspan="2">Code:
MScTI_SEM</td><td colspan="3">Course Title:
Advanced Seminar</td></tr>
<tr><td colspan="2">Lecturer:
all groups</td><td colspan="3">Type:
Seminar with Presentation</td></tr>
<tr><td>Credit Points:
4 + 2 (soft skills)</td><td>Workload:
180h</td><td>Teaching Hours:
2 / week</td><td>Language:
German, maybe English</td><td>Term:
WS</td></tr>
<tr><td colspan="5">Module Parts and Teaching Methods:
Seminar</td></tr>
<tr><td colspan="5">Objectives: After this course the students will be able to:
Search literature for a specific subject,
Select subject / material for a presentation,
Prepare material (slides) for a presentation,
Give a scientific presentation.</td></tr>
<tr><td colspan="5">Contents:
Literature research
Preparation of presentation
Oral Presentation (~45 Minutes)
Preparation of a short summary report (~10 pages)
Active participation in other student’s presentations & discussion</td></tr>
<tr><td colspan="2">Prerequisites:
none</td><td colspan="3">Recommended Knowledge:
General Knowledge about the chosen field</td></tr>
<tr><td colspan="5">Literature:
Partially provided by lecturer</td></tr>
<tr><td colspan="5">Form of Testing and Examination: Presentation, Short Summary, Regular active participation</td></tr>
</table>

Code: MScTI_SA		**Course Title:** Student Research Project		
Lecturer: all groups		**Type:** Practice Course		
Credit Points: 14	**Workload:** 420h	**Teaching Hours:** n.a.	**Language:** n.a.	**Term:** WS/SS

Module Parts and Teaching Methods:

- Practical Course

Objectives: After this course the students will be able to:

- Dig into scientific and technical aspects of a selected topic,
- Manage and carry through a small research project,
- Write a medium length report.

Contents:

- Research work on a specific topic.
- Management of work.
- Preparation of a medium length report.

Prerequisites: none	**Recommended Knowledge:** Knowledge in research field

Literature:

Depending on subject. Provided by supervisor

Form of Testing and Examination: Written Report

Code: MScTI_THESIS		**Course Title:** Master Thesis		
Lecturer: all groups		**Type:** Practice Course		
Credit Points: 30	**Workload:** 900h	**Teaching Hours:** n.a.	**Language:** n.a.	**Term:** WS/SS

Module Parts and Teaching Methods:

- Master Thesis

Objectives: After this course the students will be able to:

- Manage and carry through a large research project,
- Write an extended thesis,
- Report on own scientific work in an oral presentation.

Contents:

- Research work on a specific topic.
- Management of work.
- Preparation of a longer written thesis.
- Oral presentation in the Colloquium.

Prerequisites:	**Recommended Knowledge:**
none	Knowledge in research field

Literature:

Depending on subject. Provided by supervisor

Form of Testing and Examination: Written thesis, Colloquium